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USING THE CYPRESS CREEK FORMULA TO ESTIMATE RUNOFF RATES IN THE SOUTHERN COASTAL PLAIN AND ADJACENT FLATWOODS LAND RESOURCE AREAS

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Using the Cypress Creek Formula to Estimate Runoff Rates in the Southern Coastal Plain and Adjacent Flatwoods Land Resource Areas[1]

John C. Stephens and W. C. Mills[2]

INTRODUCTION

The Problem

The Cypress Creek formula, $Q = C\ M^{5/6}$, is employed by many engineers as a means of determining design capacity for drainage canals. In this formula, Q is the average runoff rate in cubic feet per second for the 24-hour period of greatest runoff for a storm event; M is drainage area in square miles; and C is a coefficient mainly dependent upon degree of protection desired.

Questions often arise concerning the capability of the exponent 5/6 in the Cypress Creek formula to compensate for differences in size of drainage areas, and how to select values of C for the protection desired. These questions are considered here for the Southern Coastal Plain, Atlantic Coast Flatwoods, Gulf Coast Flatwoods, and Southern Florida Flatwoods major land resource areas.

Background

The nature of flood flow has been found to depend on the physiographic and climatologic characteristics of the streams' drainage basin. This relationship can be expressed by an equation such as the following: $Q\ max. = C\ .\ A^x\ .\ B^y\ .\ C^z \ldots N^n$ (1)[3]. In this equation Q max. is peak flow for a given return frequency period, C a coefficient depending upon return frequency, and A, B, C ....N are measurable characteristics of the basin, such as size, main-channel gradient, land slope, etc., where the effect of the measurable basin characteristics are the power functions x, y, z ....n. We have learned that the dominant, and often the only obtainable, basin characteristic of significance is size. In this case, the complex general equation may be reduced to the more tractable relation, $Q = CA^x$, which is similar in form to the Cypress Creek formula, since A represents drainage area as does M in the Cypress Creek formula.

Some runoff formulas assume peak rates to vary as the square root of the area, i.e., $M^{1/2}$. The widely used Talbot "culvert formula" assumes runoff to vary as $M^{3/4}$. Engineers sometimes tacitly regard M as a linear factor and vary other coefficients to conform with location conditions. Unitgraph theory (5) states that if two watersheds are hydraulically similar in all respects, then (mathematically) the horizontal dimensions (time) of the unitgraph are in the same ratio as the one-fourth power of the areas and the vertical dimensions (discharge) are in the same ratio as the three-fourths power of the areas. Thus, peak runoff would vary as $M^{3/4}$.

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[1] Soil and Water Conservation Research Division, Agricultural Research Service, U.S. Department of Agriculture, in cooperation with the Florida Agricultural Experiment Station and the Central and Southern Florida Flood Control District.

[2] Leader, Watershed Engineering Investigations, and research agricultural engineer, both of Southern Branch, Soil and Water Conservation Research Division, Agricultural Research Service; at Athens, Ga., and at Plantation Field Lab., Fort Lauderdale, Fla., respectively.

[3] Underscored numbers in parentheses refer to Literature Cited at end of this report.

Peak instantaneous discharges have been plotted against drainage-area size on log-log graph paper by the U.S. Geological Survey (8) for several groups of watersheds in the Southeastern States. Examination of the graphs by the writers showed that straight-line regression equations with slopes ranging from 0.43 to 0.84 for individual watersheds fitted the plotted data. For most of these watersheds, however, the regression-line slopes were between 0.65 and 0.80, and averaged 0.71. The regression-line slope, thus plotted, represents the value of the exponent x in M^x. While this average slope value of 0.71 indicates general agreement between unit-graph theory and actuality, ($x = 0.75$) it does not answer the specific questions posed about the exponent in the Cypress Creek formula.

Present Practice

Normally the value of the coefficient C is selected to give the flow rate that provides optimum drainage at the least cost by weighing expenditures for construction and maintenance against the occasional loss of a crop or structure. Since loss of life is not involved, protection is not provided for the maximum probable flood, and seldom for floods that occur only rarely. Selections of C values are therefore essentially a calculated risk based on available information and the engineer's best judgment.

In practice,[4] "The design runoff is planned to flow below the design hydraulic gradient, which is generally set one foot below average field levels for major drainage ditches. Such ditches therefore have reserve capacity before flooding occurs at average field level, and this reserve exists for some years after construction. During this period peak discharges often exceed the design capacities. After ditches partially fill with sediment, or are obstructed by vegetation, this safety factor ceases to exist.

"Due to irregularities in topography the hydraulic gradient is near or above the elevation of low areas, which are expected to flood when the ditch is at design stage, and such areas thus act similar to a detention reservoir. Such areas do not receive full drainage protection and often are used for pasture or woodland. Woodland and pasture land do not require the same degree of drainage as cropland and ditching of such lands is usually less intensive. Some land can be flooded at shallow depths for more than 24 hours with negligible damage to some crops. The area and duration of flooding affect the amount of soil storage utilized. Also, flooding that occurs during the nongrowing season may cause no crop damage. Too, farm drains are improved slowly over a period of years, usually after main drains are installed. These are some of the factors that cause a very complex relationship between rainfall, runoff, soil storage, surface storage, and the designed ditch capacity to be provided for optimum results for a drainage system."

The Soil Conservation Service (9) suggests that the maximum 24-hour-average flow for the 2- to 5-year recurrence frequency be used as a guide in selecting drainage coefficients for general crops. For the coastal plains in the Southeast, C values of 10 for forest, 25 for improved pasture, and 45 for general crops are presently recommended, with additional drainage capacity advised for good protection in hilly areas.

EXPERIMENTAL WATERSHEDS

Location

Three experimental watersheds were studied to evaluate the suitability of 5/6 as the exponent of M, and to develop the relation of C to probable flood recurrence frequency. These watersheds, operated by the Soil and Water Conservation Research

[4] Personal communication from John G. Sutton, drainage engineer, Engin. Div., Soil Conserv. Serv., Wash., D.C., Dec. 1963.

Division, Agricultural Research Service, and cooperating agencies, and located in the Southern Florida Flatwoods major land resource area, near Lake Okeechobee and Vero Beach, Fla., are judged to be representative in many ways of the Gulf Coast and Atlantic Coast Flatwoods, and of level, sandy parts of the Southern Coastal Plain. The location of the experimental watersheds and these major land resource areas, as mapped by the U.S. Soil Conservation Service, are shown in figure 1.

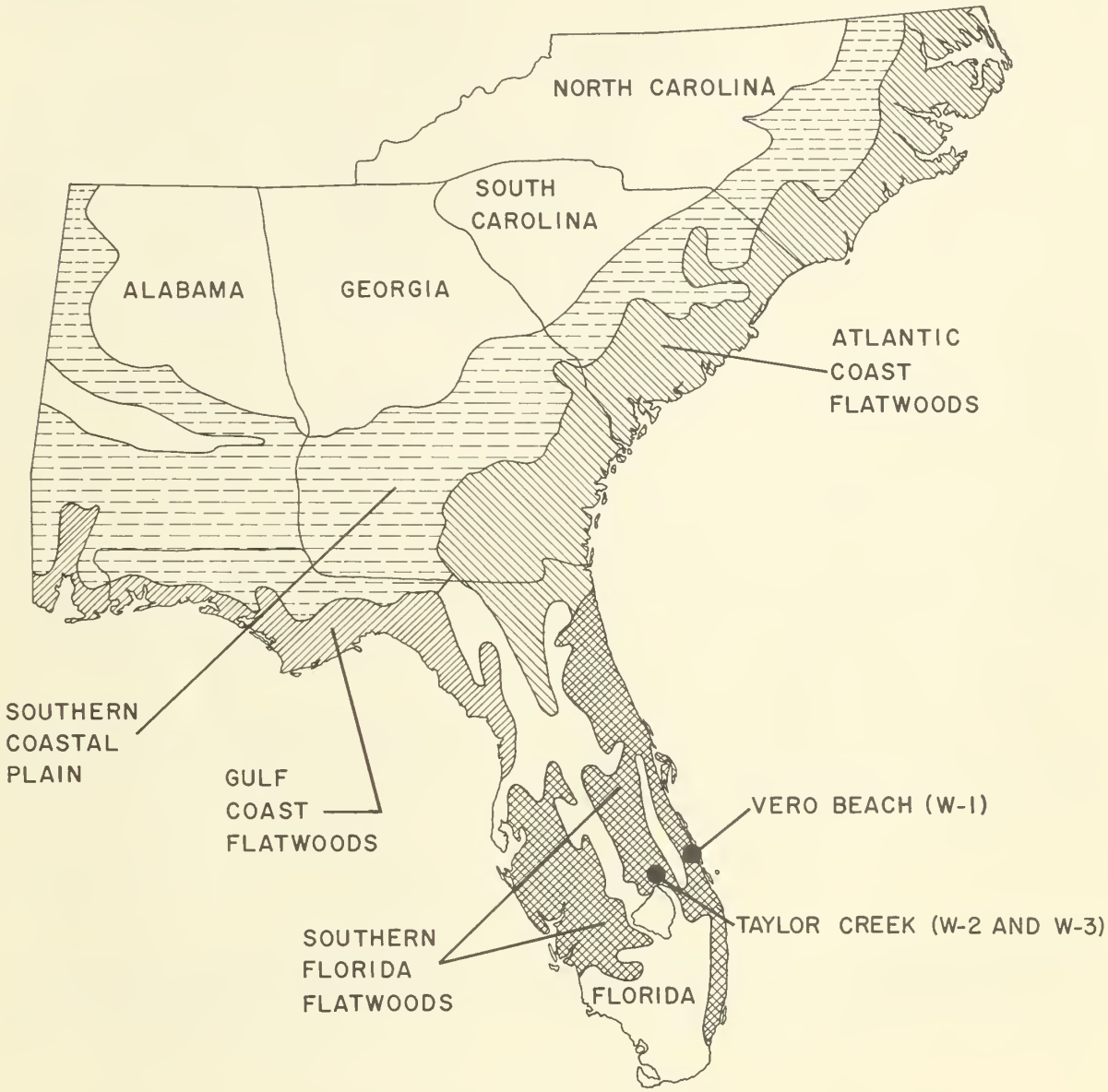

Figure 1.--Location of experimental watersheds (W-1, W-2, and W-3) in relation to associated major land resource areas.

Description

The three watersheds are all relatively flat, with slopes in the 0- to 2-percent class. The soils are typically sandy; their infiltration and internal drainage are good, if not retarded by high water tables. Little surface runoff occurs until soils become saturated. Where there is no manmade drainage, the water table is normally close to the surface. Rainfall and runoff on all three basins are measured by a network of recording raingages and by continuous streamstage recorders. Measured rainfall over the watersheds is averaged by the Thiessen method.

Vero Beach watershed, W-1, in figure 1, surrounds the city of Vero Beach, Fla., but city drainage is not a significant factor in runoff. The watershed is roughly triangular, with an area of 78.0 square miles. This area has been under artificial drainage for many years with a well maintained network of 419 miles of interconnected ditches drained by gravity to tidewater through three outfall canals. The entire area is shielded from outside surface inflow by dikes. It is highly developed agriculturally, with approximately 40 percent of its area in citrus groves, 32 percent in pasture, and 28 percent in unimproved range, forest, and miscellaneous land.

Taylor Creek watershed, W-2, is just north of, and empties into, Lake Okeechobee. The watershed is broadleafed in shape, with an area of 98.6 square miles. It is a natural watershed with poor surface drainage and contains numerous ponds and sloughs. The basin is relatively undeveloped agriculturally, with about 1 percent of its area in cropland, 29 percent in improved pasture, 64 percent in unimproved rangeland and forest, and 6 percent in marsh and miscellaneous land.

Upper Taylor Creek watershed, W-3, a subarea of Taylor Creek watershed, is its northernmost tributary. It is roughly rectangular, with an area of 15.6 square miles. Surface drainage is generally poor. The main stream cuts through Pleistocene marine terraces, producing a landscape with steplike effect between broad plateaus. Subwatershed W-3, like its parent, watershed W-2, is relatively undeveloped agriculturally, with about 1 percent of its area in cropland, 63 percent in improved pasture, 35 percent in rangeland and forest, and 1 percent in miscellaneous land.

These watersheds and rainfall-runoff relations, annual maximum flows, and particulars on selected storm events in these areas are described in detail in a publication of the Agricultural Research Service (8).

Generally stated, the three watersheds are representative of soil and slope conditions in the Southern Florida Flatwoods for agricultural watersheds ranging in size from 15 to 100 square miles. However, they are at decidedly different stages of development in drainage and agriculture.

HYDROLOGIC ANALYSIS

Hydrologic data collected for 10 years on Vero Beach watershed, W-1, and 5 years on the Taylor Creek watersheds, W-2 and W-3, were analyzed in this study.

Computing Rainfall Excess

To provide a means of comparing rainfall-runoff relations for different storm events on the three watersheds, it was first necessary to obtain a rainfall excess value for each storm. This was done by applying the moisture-budget method, as explained in the following paragraph, to the 30-day period prior to each major storm event.

Soil moisture was found to decrease during rain-free periods in accord with the equation $I_t = I_o K^t$, where I_o is the initial amount of water in storage, I_t is the reduced amount t days later, and K is a recession factor. Values of K equal to 0.96 for winter months and 0.94 for other months were obtained from observed ground-water

recession curves and laboratory-determined desorption curves. Water stored in the soil was then calculated on a daily basis, assuming the water table was at ground surface with 5 inches of evaporable water in storage 30 days prior to storm runoff. This assumption was, of course, not strictly true in most cases; however, over a 30-day period the effect of this error was negligible. The rainfall excess was found by subtracting the water storage space available in the soil at the beginning of the storm event from the total storm rainfall.

Establishing M^x Relations

A graphical analysis of the equation $Q = C\ M^x$ was made by plotting on log-log graph paper annual maximum 24-hour-average runoff rates against watershed areas for the 10 annual maximum storms for Vero Beach (1951-60), and the 5 annual maximum storms for both Taylor Creek watersheds (1956-60). Figure 2 shows the resultant equations fitted to peak daily flows from rainfall excess amounts of 7, 5, and 2 inches. The corresponding total rainfalls for the individual storms were approximately 10, 8, and 5 inches. Since most of the storms lasted about 24 hours, such events were estimated, from rainfall frequency charts (4), to occur on an average of once in 50, 10, and 2 years, respectively, at the watershed sites.

The best fitting equation, $Q = 131\ M^{0.83}$, was obtained from maximum 24-hour-average runoff rates following the largest storms of record. The two lower lines, $Q = 115\ M^{0.79}$ and $Q = 97\ M^{0.63}$, were located by interpolation for computed rainfall excess amounts of 5 and 2 inches.

Establishing C Values

Values of the coefficient C in the Cypress Creek formula were computed from annual maximum 24-hour-average runoff rates for the three experimental watersheds by the formula $C = \frac{Q}{M^{5/6}}$

Regression of C on Rainfall Excess

The next step was to evaluate the coefficient C in terms of rainfall excess, and thereafter relate both to probable storm recurrence periods. First, values of C were plotted as a function of rainfall excess for all major storms, as shown in figure 3. Based on 20 runoff events, and computed by the method of least squares, the regression equation was

$$y = 16.39 + 14.75x$$

where y is the predicted value of the coefficient C and x is the rainfall excess (inches) for the individual storm periods. The coefficient of regression r, of determination r^2, and the 50- and 95-percent confidence levels (C.L.) were determined by standard statistical procedures (7).

Establishing Recurrence Intervals

From storm frequency.--The estimated return frequency of rainfall excess, shown superimposed on the x-axis in figure 3, was derived from the relation of rainfall excess to total storm rainfall, and the established statistical frequency of the latter. These rainfall excess frequencies are essentially the return frequencies of 24-hour rainfall amounts for the vicinity of the experimental watersheds in southern Florida (4), with approximately 3 inches subtracted for soil storage. This abstraction varied somewhat, depending on antecedent rainfall, but the 3-inch volume gave the best fit.

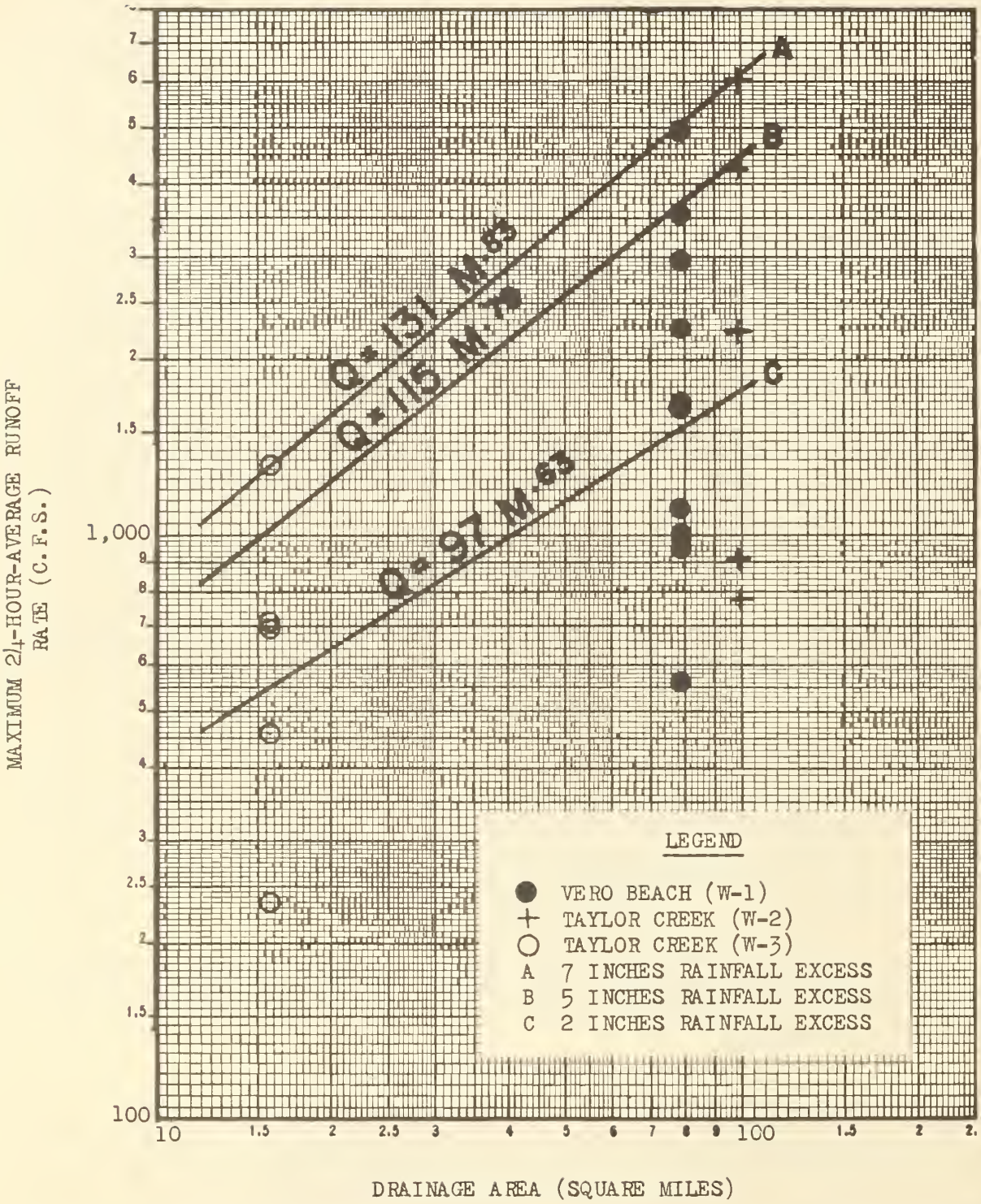

Figure 2.--Relation of annual maximum 24-hour-average runoff rate to drainage area for three experimental watersheds in southern Florida.

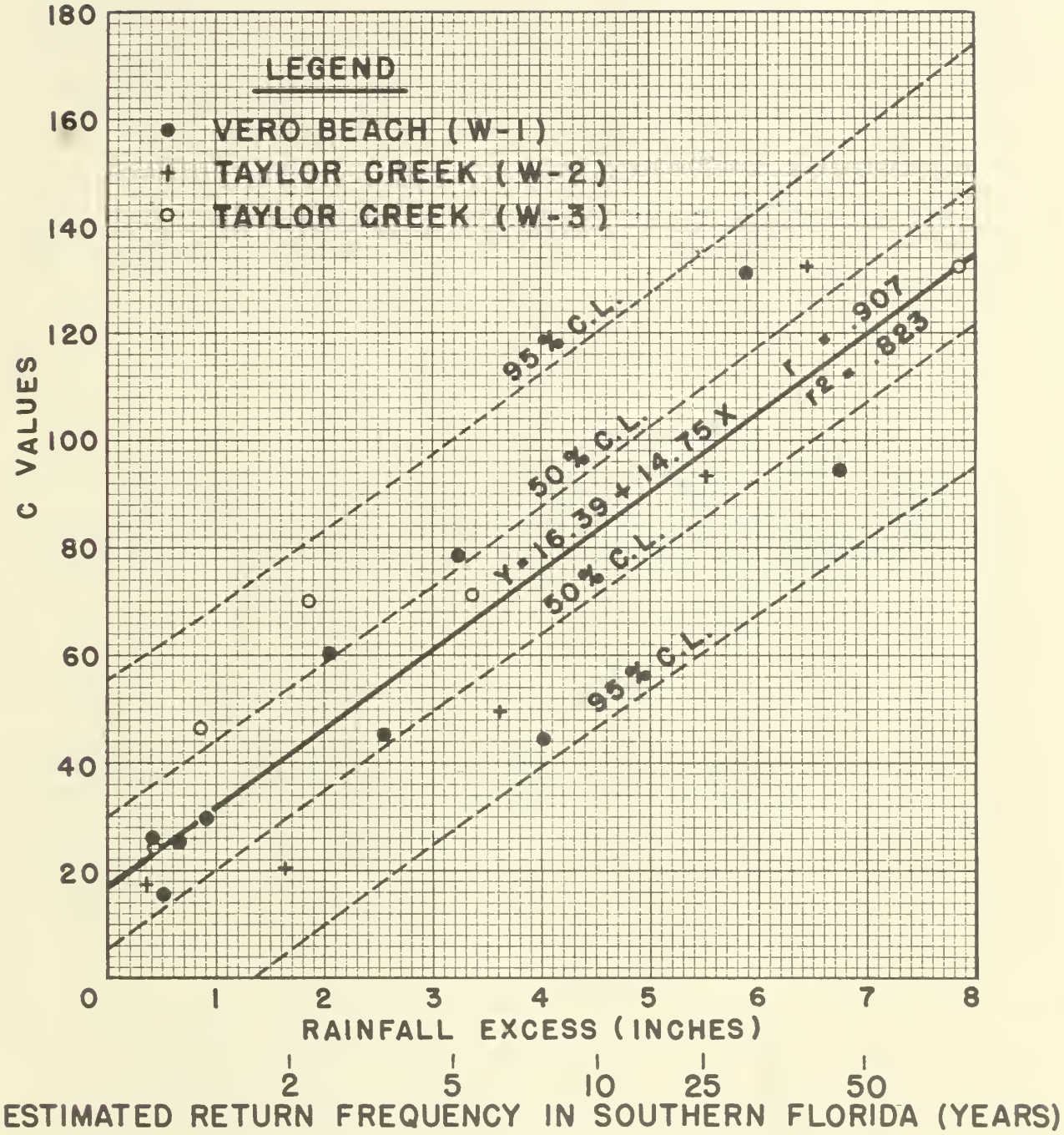

Figure 3.--Values of C in the Cypress Creek formula, $Q = C\ M^{5/6}$, versus rainfall excess for three experimental watersheds in southern Florida.

From runoff frequency.--The method of obtaining return frequency of various size runoff events from storm frequencies was checked by the Hazen method, that is, the maximum 24-hour-average flow rate for each year was plotted on logarithmic, normal-probability paper. The resultant flood-frequency line indicated the size of flood expected.

Computed values of C derived by the Hazen method from the 10-year runoff record for the Vero Beach (W-1) watershed compared reasonably close to corresponding values of C obtained through use of the storm-frequency method, shown in figure 3. On the other hand, the 5-year runoff record for both Taylor Creek watersheds (W-2 and W-3) yielded higher C values with the Hazen method, than with the storm-frequency method. The Hazen method C values were probably unrealistically high. Since Benson (1) found that a minimum record of 12 years is needed to establish the "mean-annual flood"[5] (return frequency of 2.33 years) within an accuracy of 25 percent of the 95-percent confidence level, it is no surprise to find results from the 5-year records at variance. Furthermore, when the 5-year Taylor Creek records were normalized by using the maximum runoff of 1956 as the 50-year event (as established on nearby streams with longer records), flow frequencies were reasonably consistent with the Vero Beach results, and consequently in line with the concomitant C values shown on the graph in figure 3, derived purely from rainfall frequency.

RESULTS AND DISCUSSION

Selecting an Exponential Term

The validity of the exponent in the Cypress Creek formula $Q = C\ M^{5/6}$ for the 50-year frequency storm is indicated by the excellent fit of the regression line $Q = 131\ M^{0.83}$ in figure 2. However, it has been postulated that the value of the exponent varies with the intensity of the storm. For example, Benson's studies (2) in the northeast showed the exponent of area to vary from 0.85 for the 2.33-year recurrence interval to 0.68 for the 50-year recurrence interval. On the other hand, the interpolated regression lines of figure 2, which show relations of Q equal to $115\ M^{0.79}$ and $97\ M^{0.63}$ for rainfall excess amounts of 5 inches and 2 inches, respectively, indicate a reversal of this order for southern Florida. However, the actual plotted points give too much scatter for these two regression lines to be significantly meaningful in contrast to the good fit of the uppermost line of figure 2.

It is therefore considered prudent to accept the uppermost line, $Q = 131\ M^{5/6}$, which will give conservative values for runoff, as the proper form for expressing flow from such watersheds. Thus, it is recommended that the exponent 5/6 be retained, and the value of the coefficient C be adjusted to give proper runoff rates for lesser storms. That is to say, the formula $Q = C\ M^{5/6}$ will give safe and reasonably accurate maximum 24-hour-average runoff rates for watersheds of different size with appropriate values of C.

Selecting Design Values of C

Assuming the present form of the Cypress Creek formula to be correct, the problem is to select values of C suitable for outlet design. This usually entails making a selection based on a consideration of runoff-recurrence probability and drainage cost of the most economical value of C.

For the Experimental Watershed Areas

For neighboring areas with soil and rainfall similar to that of the experimental sites, values of C can best be selected from the relation $C = 16.39 + 14.75\ R_e$, which gives C as a function of rainfall excess R_e. In turn, the expected 2-, 5-, 10-, 25-, and 50-year recurrence intervals for various rainfall-excess values can be obtained directly from the x-axis in figure 3.

[5] The term "mean-annual flood" is used here to conform with usage established by the U.S. Geological Survey. It is defined (3) as the 2.33-year flood from the graphic frequency curve.

A value of 0.907 for the correlation coefficient r in the prediction equation is considered good for runoff studies of this type, and a coefficient of determination, r^2, equal to 0.827 indicates that nearly 83 percent of the variation in C values may be ascribed to concomitant variation in rainfall excess.[6] This indicates that watershed area is by far the dominant factor influencing maximum runoff rates, leaving only about 17 percent of the remaining variation to be explained by other watershed characteristics or conditions, if rainfall excess is adequately known.

Similarly, Benson (2), in a detailed analysis of longterm records from 164 diversified New England watersheds, ranging in size from 1.64 to 9,661 square miles, found that the equation $Q_{2.33} = 44.4\ A^{0.85}$ was sufficient to account for 84 percent of the concomitant variations in predicting peak values for mean-annual (2.33-year frequency) floods in that region. Significant also was his finding that addition of a channel-slope factor to watershed size raised the r^2 value to 0.920, indicating that these two factors alone accounted for 92 percent of concomitant variation in maximum runoff rates between watersheds.

Taken together, the Florida and New England results point out that adjustments to predict changes in maximum flow peaks due to watershed treatment, with the possible exception of channel betterment, are hardly justified for storm recurrence intervals of 2.33 years or more, unless detention pools are included in the improvements.

When the prediction equation in figure 3 is used to compute runoff rates from homologous areas in the Southern Florida Flatwoods, the accompanying confidence limits are useful in estimating the expected degree of safety. For example, one would normally expect 25 percent of the maxima in a given time period to exceed the upper 50-percent confidence limit, and 2.5 percent to exceed the upper 95-percent confidence limit for respective time periods associated with the given probability values.

For Other Areas in the Southern Coastal Plains and Adjacent Flatwoods Land Resource Areas

Working hypothesis.--Consider now the applicability of C coefficients derived from figure 3 to the design of channels in other sandy flatwoods areas. Values of C in figure 3 are in direct proportion to the 24-hour rainfall amounts in excess of the capacity for rainfall storage. Hence, for homologous watersheds at similar antecedent moisture conditions, the value of C and associated peak flows should vary with the 24-hour rainfall rates.

The 10-year, 24-hour isopluvial map for the region under discussion (fig. 4) is adapted from a U.S. Weather Bureau publication (4). The experimental watersheds lie in an area of medium-high rainfall intensity between the Atlantic and Gulf Coast regions. From this and similar isopluvial maps the maximum expected 24-hour rainfalls for the 2-, 10-, 25-, and 50-year recurrence intervals at the experimental sites were found to be 4.75, 7.50, 8.50, and 10 inches, respectively. The inches of rainfall excess shown in figure 3 were derived by subtracting the 3 inches of storage normally available from these rainfall values.

This 10-year recurrence-interval isopluvial map (fig. 4) shows that maximum expected 24-hour rainfalls for the lower Gulf Coast are somewhat higher, and for the South Atlantic Coast somewhat lower than at the Florida experimental sites. The same trend holds for storms ranging from the 2- to 100-year return frequency. Therefore, other conditions being equal, applicable values of the coefficient C in the Cypress Creek formula should increase along the lower Gulf Coast and decrease along the South Atlantic Coast in accord with differences in the maximum expected 24-hour rainfall for any given recurrence interval.

Southern Florida example.--To illustrate, a 100-square-mile watershed is adopted as a standard for comparative purposes, and maximum 24-hour-average flow rates for the Southern Florida Flatwoods are computed from C values in figure 3

[6] But not necessarily to return frequency, since these estimates were superimposed on the chart from other information.

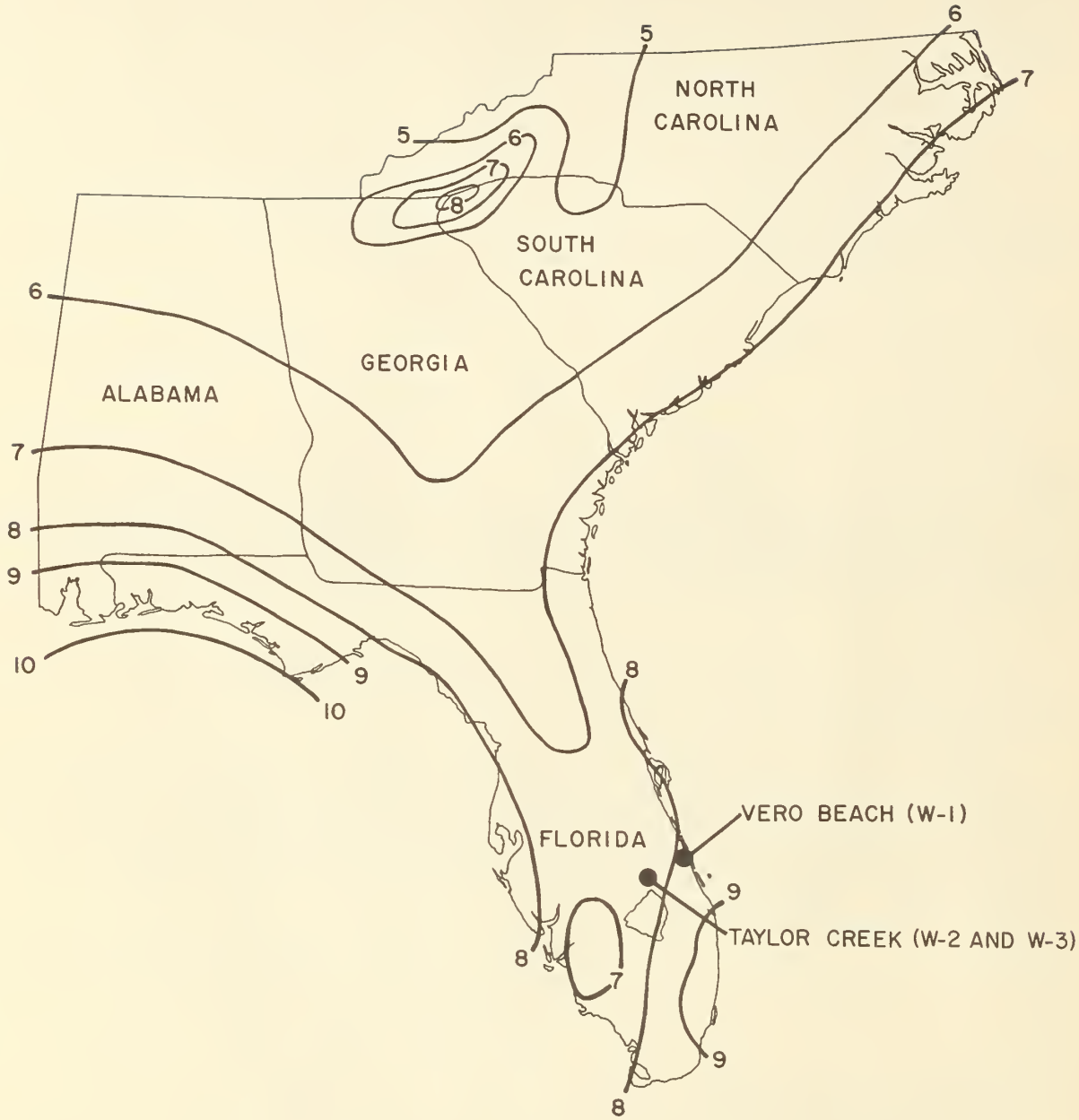

Figure 4.--Maximum expected 24-hour rainfall (inches) for 10-year recurrence interval.

for the mean annual ($\underline{Q}_{2.33}$), the 10-year ($\underline{Q}_{10}$), and the 25-year ($\underline{Q}_{25}$) frequency as follows:

$$\underline{Q}_{2.33} = 44 \times 100^{0.833} = 2{,}040 \text{ c.f.s.}$$
$$\underline{Q}_{10} = 83 \times 100^{0.833} = 3{,}850 \text{ c.f.s.}$$
$$\underline{Q}_{25} = 98 \times 100^{0.833} = 4{,}550 \text{ c.f.s.}$$

North Carolina example.--For the same size watershed in the lower coastal plains of North Carolina, the 2-year recurrence-interval isopluvial line is

approximately 1 inch less than at the Florida sites; the 10-year recurrence-interval line (fig. 4) is 1 1/2 inches less, and the 25-year recurrence-interval line also 1 1/2 inches less. When the capacity for rainfall storage is the same, the corresponding C values are found from figure 3 by shifting toward lower values on the x-axis by these reduced amounts; i.e., 1, 1 1/2, and 1 1/2 inches. A vertical line is projected upward from each point to meet the regression line, and then a horizontal line to the y-axis to obtain C. The resulting computed flows are:

$$Q_{2.33} = 30 \times 100^{0.833} = 1{,}390 \text{ c.f.s.}$$
$$Q_{10} = 61 \times 100^{0.833} = 2{,}830 \text{ c.f.s.}$$
$$Q_{25} = 76 \times 100^{0.833} = 3{,}530 \text{ c.f.s.}$$

Northwestern Florida example.--For a similar watershed along the Gulf Coast in northwestern Florida, near the Alabama State line, where the 2-, 10-, and 25-year, 24-hour storm rates are increased by 1 1/4, 2, and 2 1/2 inches, the C values are found by advancing these amounts on the x-axis, and again projecting an upward, vertical line to meet the regression line, and a horizontal line to the y-axis to obtain C. Computed flows are:

$$Q_{2.33} \quad 61 \times 100^{0.833} = 2{,}830 \text{ c.f.s.}$$
$$Q_{10} \quad 112 \times 100^{0.833} = 5{,}280 \text{ c.f.s.}$$
$$Q_{25} \quad 137 \times 100^{0.833} = 6{,}360 \text{ c.f.s.}$$

Thus, by simply adjusting for differences in 24-hour rainfall intensity, the predicted flow rates for the Atlantic Coast Flatwoods are about 75 percent, and for the Gulf Coast Flatwoods about 140 percent of those indicated for a 100-square-mile watershed in the Southern Florida Flatwoods in the Lake Okeechobee-Vero Beach area.

Appraisal of Formula

It is of interest to appraise the formula derived from these experimental studies in comparison with actual design values, which are based on 15 to 25 years of experience, used by drainage project engineers. The prediction formula, $C = 16.39 + 14.75\, R_e$, can be transposed and solved to obtain values of rainfall excess. By use of such a method an assigned C value of 45 corresponds to an R_e value of 1.95, or approximately 2 inches. Where the rainfall storage capacity is 3 inches, as indicated by the Florida studies, a 24-hour storm of approximately 5 inches is signified. Therefore, a C coefficient of 45 would normally provide protection against storms of this intensity.

Figure 5, adapted from the U.S. Weather Bureau rainfall frequency atlas (4), shows the location in the southeastern coastal plains region of both the 2- and 5-year recurrence-interval isopluvial lines for the 5-inch, 24-hour storm. Thus, the Soil Conservation Service's suggestion, previously mentioned, of using a C value of 45 for general crops for a 2- to 5-year storm recurrence frequency is seen to give the desired degree of protection between these two isopluvial lines, which inclose much of the southeastern coastal plains region. For local conditions where water table levels or infiltration rates are meaningfully different from the experimental norm, the 3-inch values of rainfall storage capacity would be affected, and adjustments required to obtain the correct rainfall excess, R_e, and the concomitant value of C.

Comparison of Flows Computed by the Cypress Creek Formula Versus the Regional Flood Frequency Method

As a check, flow rates computed by the Cypress Creek formula were compared with those computed by the regional flood frequency method developed by the U.S. Geological Survey (3).

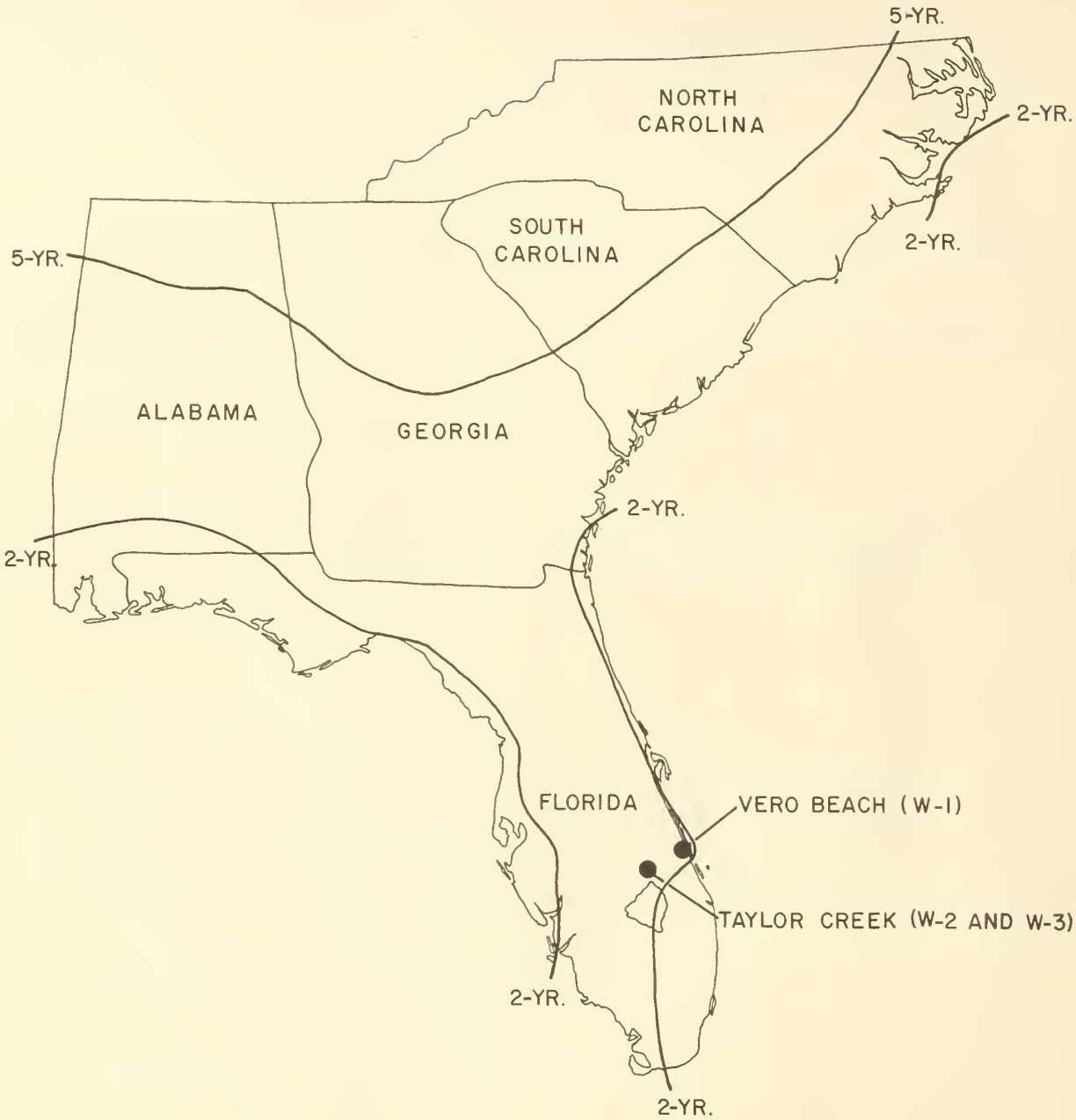

Figure 5.--Location of 5-inch, 24-hour storm isopluvial lines for 2- and 5-year recurrence intervals.

The Regional Flood Frequency Method

Essentially, the regional flood frequency method applies statistical and hydrologic theory to past flood records of selected stream basins to define: (a) curves relating the mean annual ($\underline{Q}_{2.33}$) index flood to basin characteristics, and (b) composite curves relating discharge, expressed as a dimensionless ratio, of the index flood to other recurrence intervals for streams in certain areas. That is, specific stream records are grouped together and generalized to represent the flood regime for broad,

related hydrologic areas. This method is completely different from the Cypress Creek approach.

Peak flow rates for the standard 100-square-mile basin calculated by the regional flood frequency method for 18 hydrologic areas of the coastal plains of North Carolina, South Carolina, Georgia, Florida, and Alabama are given in table 1. Delineation of the individual hydrologic areas is shown in figure 6. These flow rates were computed from material in individual State reports (6) and correspondence.[7]

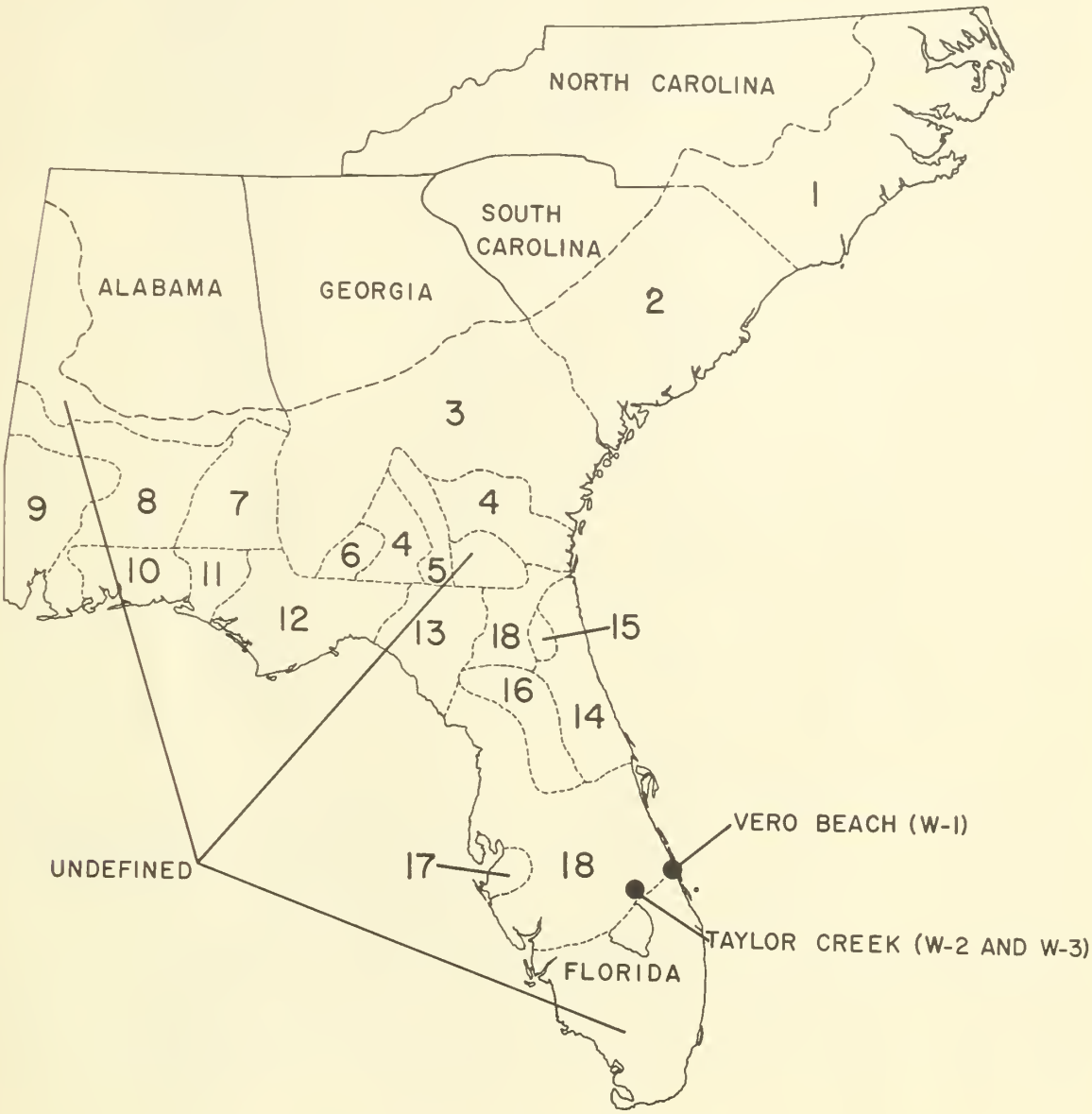

Figure 6.--Hydrologic areas as designated by U.S. Geological Survey according to flood characteristics.

[7]Forest, W. E., and Speer, P. R. Floods in North Carolina - magnitude and frequency. U.S. Geol. Survey. Open File Rpt., Raleigh, N.C. 1961.

Bunch, C. M., and McGlone, P. Floods in Georgia - magnitude and frequency. U.S. Geol. Survey. Open File Rpt., Atlanta, Ga. 1962.

Pride, R. U. Floods in Florida - magnitude and frequency. U.S. Geol. Survey. Open File Rpt., Ocala, Fla. 1958.

Personal communication from A. E. Johnson, Dist. Engin., U.S. Geol. Survey. Water Resources Div., Surface Water Br., Columbia, S.C. Sept. 1963.

TABLE 1.--Instantaneous peak flow rates as computed by U.S. Geological Survey regional flood frequency method for a 100-square-mile watershed

Hydrologic area [1]	Recurrence interval		
	2.33-yr. ($Q_{2.33}$)	10-yr. (Q_{10})	25-yr. (Q_{25})
	C.f.s.	C.f.s.	C.f.s.
1	800	1,560	2,140
2	830	1,580	1,780
3	1,170	2,620	3,010
4	1,170	2,800	3,910
5	1,370	3,270	4,560
6	2,800	6,690	9,352
7	2,340	5,030	6,460
8	3,100	6,660	8,560
9	5,000	10,750	13,800
10	3,400	7,515	10,370
11	2,620	5,790	8,000
12	1,320	2,920	4,020
13	1,000	2,210	3,050
14	1,900	3,225	4,180
15	3,700	6,480	8,140
16	1,200	2,100	2,640
17	3,700	8,180	11,280
18	1,900	4,200	5,800

[1] Defined in figure 6.

Each of the 18 hydrologic areas of figure 6 is considered to be homogenous because the streams within each area have similar flood characteristics. These areas are defined on a broadscale, drainage-basin pattern, and while they are generally related to major physiographic provinces and land resource areas, it is not uncommon for them to cut across the lesser geomorphological units.

For comparison later with examples worked out by the Cypress Creek formula, the mean annual flood ($Q_{2.33}$), the probable 10-year flood (Q_{10}), and the probable 25-year flood (Q_{25}) for a 100-square-mile watershed are shown for each area in table 1. However, these are instantaneous peak flows, whereas the Cypress Creek formula estimates the maximum 24-hour-average flow rate, so the two may not be strictly comparable.

Instantaneous Peak Versus Maximum 24-Hour-Average Flows

The amount the instantaneous peak-flow rate exceeds the maximum 24-hour-average flow rate depends on watershed size and storm intensity. For large watersheds and high-volume storms the two rates differ little, but the spread becomes greater as watershed size and 24-hour storm intensities decrease. The effect of watershed size is shown in figure 7, for the several previously described experimental watersheds, and for a nearby watershed (Monrieve Ranch) of approximately

6 square miles with a short-term runoff record. For this graph, the 76-square-mile Vero Beach watershed (W-1), drained by an interconnected network of ditches through three main outfall canals, was arbitrarily divided into three equal basins of 26 square miles each; the flow rates for W-1 are an average of rates for the three outlets. The resulting graph (fig. 7) gives a smooth curve with increasing spread of the 95-percent confidence levels as the watersheds become smaller.

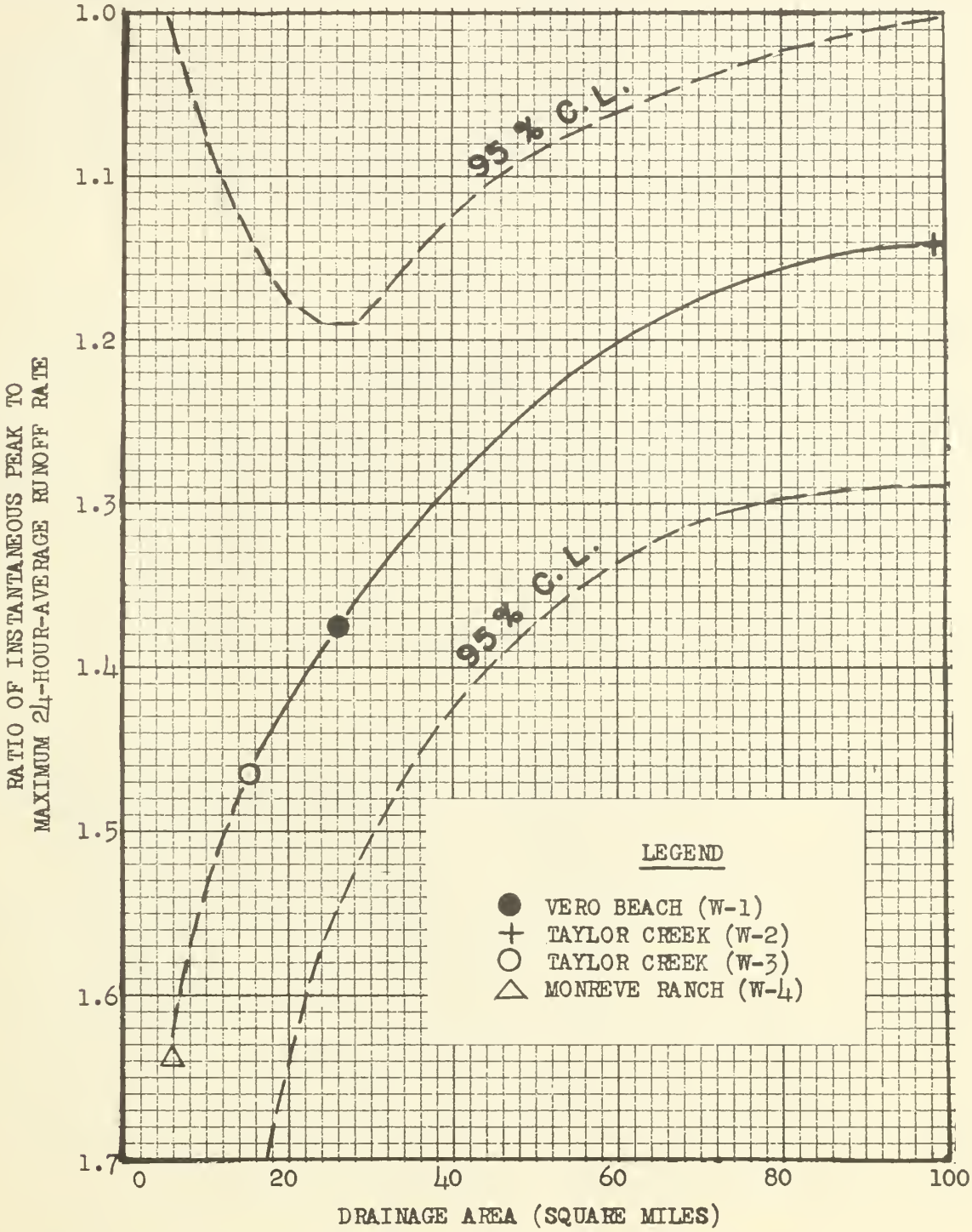

Figure 7.--Ratio of instantaneous peak to maximum 24-hour-average runoff rates in relation to drainage area for four experimental watersheds in southern Florida.

Comparison of Computed Maximum Flood Flows for Three Selected Hydrologic Areas

The ratio of the instantaneous peak to the 24-hour-average flow rate for the 100-square-mile watershed has been accepted, from the curve (fig. 7), as 1.14. This value is used in table 2 to convert maximum 24-hour-average flow rates previously computed by the Cypress Creek formula for the southern Florida, northwestern Florida, and North Carolina areas to instantaneous peak flows for comparison with flows computed by the regional flood frequency method.

The ratios in table 2 show reasonably favorable comparison between the two methods except for the North Carolina area, where the Cypress Creek formula approach gave double the flows estimated by the regional flood frequency method. While data are not available to calculate the coefficient of variation using the regional flood frequency method, the appreciable difference in computed flows sometimes shown between two adjacent hydrologic areas in the same major watershed illustrates the wide range to be expected. For example, compare predicted peak flow rates from table 1 for adjacent hydrologic areas 6 and 12 shown in figure 6.

TABLE 2.--Comparison of peak flow rates computed by the Cypress Creek formula approach (revised[1]) and the regional flood frequency method for a 100-square-mile watershed in selected hydrologic areas of Florida and North Carolina

Recurrence interval	Southern Florida Hydrologic area No. 18			Northwestern Florida Hydrologic area No. 10			North Carolina Hydrologic area No. 1		
	Revised Cypress Creek flow	Regional flood frequency flow	Ratio of revised Cypress Creek to regional flood frequency values	Revised Cypress Creek flow	Regional flood frequency flow	Ratio of revised Cypress Creek to regional flood frequency values	Revised Cypress Creek flow	Regional flood frequency flow	Ratio of revised Cypress Creek to regional flood frequency values
	C.f.s.	C.f.s.		C.f.s.	C.f.s.		C.f.s.	C.f.s.	
$Q_{2.33}$	2,330	1,900	1.23	3,230	3,400	0.95	1,580	800	1.98
Q_{10}	4,390	4,200	1.05	6,020	7,520	.80	3,230	1,560	2.07
Q_{25}	5,190	5,800	.90	7,250	10,370	.70	4,020	2,140	1.88

[1] Cypress Creek formula rate times 1.14.

In general, the two methods are judged to give comparable results for most coastal plains areas in Florida, Georgia, and southeastern Alabama within the limits of chance inherent with hydrologic variables. On the other hand, the extreme disparity indicated by the ratio of computed flows for the coastal plains of North Carolina shows a significant difference between the two methods for that area. A similar comparison of the two methods for the coastal plains of South Carolina would also show a significant difference. The differences could result from a greater capacity for infiltration in the Carolinas than in Florida. Or, it may result from the relatively few records from small agricultural watersheds in the coastal plains of North Carolina and South Carolina available for flood frequency analyses. Other variables could contribute, but in view of the general similarity of the coastal flatwoods region, plus the high coefficient of determination, $r^2 = 0.82$, found in the experimental analyses between flood flows and excess rainfall, the most probable explanation is either (a) a meaningful difference in rainfall excess between the flatwoods region of southern Florida and North Carolina, or (b) a scarcity of streamflow records for regional flood-frequency analyses in the coastal plains of the Carolinas. Further studies are needed to clarify these differences and establish the best method for computing flood peaks and related drainage needs in these areas.

SUMMARY AND CONCLUSIONS

The Cypress Creek formula, $Q = C\ M^{5/6}$, gives reliable estimates of maximum 24-hour-average runoff rates for small agricultural watersheds in the flatwoods regions of the Gulf Coast, Atlantic Coast, and southern Florida, and in the Southern Coastal Plain--wherever rainfall excess can be determined for the maximum 24-hour storm.

Values of the coefficient C can be obtained with reasonable accuracy from the relationship $C = 16.39 + 14.75\ R_e$, where R_e is rainfall excess in inches.

Relating rainfall excess to probable recurrence periods requires judgment and knowledge of the capacity for infiltration of the soils involved. However, a useful estimate of rainfall excess is obtained in many instances by subtracting approximately 3 inches from the predicted maximum 24-hour-storm rainfall.

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